REMARKS/ARGUMENTS

In the Office Action dated May 6, 2003, the Examiner (1) rejected certain claims under 35 U.S.C. § 112, first paragraph, and (2) rejected certain claims under 35 USC § 102(b) and § 103(a) as being anticipated by or obvious over U.S. Patent No. 5,806,597 (*Tjon-Joe-Pin*). Applicants gratefully acknowledge the allowability of claims 102 and 121, and respectfully request consideration of the foregoing amendments and the following remarks and arguments, and withdrawal of the remaining rejections.

Status of the Claims

Claims 102 and 121 are allowable.

Claims 18, 28-29, 38, 50-85, 107 and 115 have been canceled.

Claims 1-3, 19-22, 30, 35-37, 39, 40, 41, 44, 46, 49, 86-88, 93-96, 98, 109 and 112 have been amended.

New claims 130-163 have been added.

Claims 1-17, 19-27, 30-37, 39-49, 86-106, 108-114, and 116-163 are currently pending.

Rejections Under 35 U.S.C. § 112, First Paragraph

In the Office Action of May 6, 2003, the Examiner takes the position that the negative limitation that appears in claims 1-17, 19-27, 30-37, 39-49, 86-101, 103-120 and 122-129 is not in the specification and therefore introduces new matter. In response, Applicants have amended claims 1-3, 40, 44, 46 and 49 to omit the negative limitation language. Each of those claims, as currently amended, includes a list of triggering signals that is fully supported in the claims and specification as originally filed. The limitation "reversal of wellbore pressure-differential" is described in the specification at page 5, lines 4-18; page 16, lines 28-31; page 20, lines 8-11; and page 48, line 30 - page 49, line 4, for example. Claim 19 has also been amended to recite "reversal of wellbore pressure-differential."

Claim 46 additionally includes "said contaminant" as a choice of triggering signal. This limitation is supported in the specification at page 48, lines 2-6, for example. Also supported by at least the same section of the specification is new claim 130 which has been added to better ensure coverage of a preferred embodiment to which Applicants are entitled.

The Examiner suggests in the Office Action with respect to claim 106, that "the solid being a perforated [*sic*] gun holder is also not taught in the specification." Applicants respectfully traverse

for the reason that this embodiment is described in the specification at page 46, lines 23-29. It is known in the art to refer to perforation guns as "perf guns," as evidenced at col. 2, lines 61-67 of U.S. Patent No. 5,615,739, a copy of which is attached hereto as "Attachment A." For better consistency of language, or to correct an obvious informality, Applicants have currently amended the specification at page 46, lines 25-26 to state "...a starch-polymer containing encapsulated enzyme could be molded into a perforation ("perf") gun holder ... ." This amendment does not constitute new matter.

New claim 131, which depends from claim 109 has been added to better ensure coverage of a preferred embodiment in which the downhole reversal of wellbore pressure-differential causes the release of CO_2 in the downhole environment whereby a change in pH results.

All of the pending claims are believed to fully comply with the requirements of 35 U.S.C. § 112, first paragraph.

<u>Rejections Under 35 U.S.C. § 102(b)</u>

In the Office Action of May 6, 2003 claims 1-5, 20, 21, 34-37, 39, 40, 43, 44, 46, 47, 86-90, 93, 95-100, 104, 105, 107, 108, 110, 112, 114, 115, 125 and 127-129 stand rejected as being anticipated by *Tjon-Joe-Pin*. The Examiner suggests that *Tjon-Joe-Pin* teaches a well treatment fluid which comprises a polymer and a sequestered enzyme, wherein the enzyme is surrounded by a complex including a polymer and crosslinker. The Examiner states that upon <u>a change in pH and temperature</u>, the enzyme in the complex becomes active and breaks the polymer, referring to col. 2, lines 38-58 of *Tjon-Joe-Pin*, which states,

> According to another aspect of the invention, a method for using the breaker-crosslinker-polymer complex in gellable fracturing fluid are provided. A preferred method for using the fracturing fluid includes pumping the fluid comprising the complex in a substantially non-reactive state to a desired location within the well bore under sufficient pressure to fracture the surrounding subterranean formation. The complex is then maintained in the substantially non-reactive state by maintaining specific conditions of pH and temperature until a time at which the fluid is in place in the well bore and the desired fracture treatment or operation is completed. Once the fracture is completed, the specific conditions at which the complex is inactive are no longer required. Such conditions that may change, for example, are pH and temperature. When the conditions change sufficiently, the complex becomes active and the breaker begins to catalyze polymer degradation causing the fluid to become less viscous, allowing the "broken" fluid to be produced from the subterranean formation to the well surface. A "broken" fluid is considered as a fluid having a viscosity of less than 10 cps at 511^{S-1}.

Tjon-Joe-Pin's Enzyme is Not Sequestered.

In reply, Applicants respectfully traverse the proposition that the *Tjon-Joe-Pin* reference teaches that "the enzyme is surrounded by a complex including a polymer and crosslinker." Applicants submit that the method disclosed by *Tjon-Joe-Pin* does not teach surrounding an enzyme with a complex including a polymer and crosslinker, but instead calls for a polymer-crosslinker-enzyme complex to be maintained under conditions where the enzyme is initially in direct contact with and acts upon the substrate. The enzyme is held inactive by virtue of competitive binding, as made plain in the *Tjon-Joe-Pin* reference at col. 4, line 61 - col. 6, line 19, which discusses non-productive binding in the enzyme-polymer-crosslinker complex. This marked difference is especially telling at col. 5, lines 1-5, where it is stated,

> The reaction rate of the intermediate enzyme-substrate complex is pH dependent and may be slowed or even virtually halted by controlling the pH and temperature of the enzyme substrate complex. [underlining added]

Not only does the *Tjon-Joe-Pin* reference not envision a substrate-degrading agent being sequestered, or in any manner kept apart from its substrate, it also specifically distinguishes its method from the use of encapsulation to inactivate an enzyme (col. 2, lines 1-6). This is in marked contrast to "sequestration" of a substrate degrading agent (*e.g.*, an enzyme), as that term is employed in Applicants' specification at page 28, lines 2-12, for example, and in Applicants' claims. *Tjon-Joe-Pin* also does not teach effecting a pH change to trigger activation of a sequestered enzyme. See, for example, claim 1 of *Tjon-Joe-Pin* which describes a method that includes "ceasing to maintain the breaker-crosslinker-polymer complex at conditions sufficient to maintain said substantially non-reactive complex, allowing polymer breakdown to be catalyzed by said breaker... ."

As indicated above with respect to the § 112, first paragraph rejections, Applicants have amended claims 1, 44 and 46 to include a list of triggering signals, including change of pH. By this amendment, it is not the intention of Applicants to disclaim that a change in temperature and/or pressure may be used in combination with the claimed triggering signals.

With respect to claim 93, in particular, it is manifestly clear that the breaker-crosslinker-polymer complex employed in the method of *Tjon-Joe-Pin* cannot anticipate the method of claim 93. In claim 93 the substrate is expressly excluded from the fluid, solid or mixture thereof containing the inactivated substrate-degrading agent. Further emphasizing certain differences between the fracturing method of the *Tjon-Joe-Pin* reference and that provided by certain embodiments of Applicants' invention, new claims 156-160, which depend respectively from claims 1, 3, 40, 44 and

46, have been added. These new claims require that the inactivated substrate-degrading agent is prepared before it is contained in the fluid, solid or mixture. Thus, the inactivated substrate-degrading agent (*e.g.*, encapsulated enzyme) can be created separately and then blended into a fluid with or without the degradable substrate. By contrast, the fracturing method of *Tjon-Joe-Pin* calls for the formation of a complex with the fluid. See, for example, *Tjon-Joe-Pin* at col. 3, line 62 - col. 4, line 4:

> Unlike the breaker system of the prior art, a new highly stable breaker-crosslinker-polymer complex has been developed that reduces premature fluid degradation while allowing the breaker to be evenly dispersed throughout the polymer. Such a stable breaker-crosslinker-polymer complex may be prepared by determining specific conditions of pH and temperature at which a specific breaker-crosslinker-polymer forms a stable complex with a matrix of compounds, each compound including a compatible breaker, polymer and crosslinker.

Tjon-Joe-Pin's Enzyme is Not Encapsulated

With respect to claims 2-5, 20, 21, 34-37, 39, 40, 43, 46, 47, 86-90, 93, 95-100, 104, 105, 108, 110, 112, 114 and 128, each of which requires that sequestration includes encapsulation, Applicants respectfully point out that the *Tjon-Joe-Pin* reference distinguishes its breaker-crosslinker-polymer complex (and its method of use) over methods and compositions that employ encapsulation of breakers for fracturing fluids. See, for example, col. 1, line 45 - col. 2, line 6; col. 2, lines 8-15; and col. 4, lines 22-25. As discussed above, the complex employed by *Tjon-Joe-Pin* appears to rely instead on a chemical association of the components and non-productive binding rather than encapsulation (col. 4, line 40 - col. 6, line 19). In contrast, one of ordinary skill in the art at the time Applicants' invention was made would recognize that the same chemical association between an enzyme and its substrate, as described by *Tjon-Joe-Pin*, would not exist in the case of an encapsulated enzyme. Applicants have also amended independent claims 3, 40 and 46 to recite the same list of triggering agents as in claim 1 and further require that sequestration of the degrading agent comprises encapsulation, which is not taught by the *Tjon-Joe-Pin* reference. It is plain that *Tjon-Joe-Pin* does not teach employing a pH change for activating an encapsulated enzyme. For at least the foregoing reasons, claims 1-5, 20, 21, 34-37, 39, 40, 43, 44, 46, 47, 86-90, 93, 95-100, 104, 105, 107, 108, 110, 112, 114, 115, 125 and 127-129 are believed to distinguish over *Tjon-Joe-Pin*.

Rejections Under 35 U.S.C. § 103(a)

Claims 1, 20 and 31-33 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over *Tjon-Joe-Pin*. The Examiner states that *Tjon-Joe-Pin* teaches a well treatment fluid which comprises

a polymer and a sequestered enzyme, wherein the enzyme is surrounded by a complex including a polymer and crosslinker. The Examiner also states that upon a change in pH and temperature, the enzyme in the complex becomes active and breaks the polymer (referring to col. 2, lines 38-58 of the *Tjon-Joe-Pin* reference, quoted above). While acknowledging that the specific enzymes of claims 31-33 are not disclosed, the Examiner takes the position that it would have been obvious to one of ordinary skill in the art to utilize the enzymes within the scope of claims 31-33, given the teachings of *Tjon-Joe-Pin* that guar and cellulose specific enzymes may be utilized as the breaker of the complex therein.

Applicant respectfully traverses and submits that claim 1 is not obvious over the teachings of *Tjon-Joe-Pin* at least for the reason that *Tjon-Joe-Pin* expressly teaches away from sequestration (*e.g.*, encapsulation) of an enzyme breaker (col. 1, lines 45-58), as discussed above with respect to the §102(b) rejections. In light of the teaching away from encapsulation in *Tjon-Joe-Pin*, one of ordinary skill in the art at the time Applicants' invention was made would expect that use of an encapsulated enzyme in a fracturing fluid would be unsuccessful. Also as noted above, *Tjon-Joe-Pin* does not teach using a pH change to trigger activation of a truly sequestered enzyme.

Moreover, while the Office Action cites the *Tjon-Joe-Pin* reference at col. 2, lines 38-58, (quoted above) as suggesting that a change in pH and temperature will activate the enzyme breaker, it should be noted that the Office Action is silent as to the teachings in the Examples and Tables of the cited reference. For instance, in Example 2 (at col. 6, lines 55-57) it is said that the results "illustrate the effect of holding this particular fracturing fluid at a pH of about 9.3 and a temperature of 250°F. on the viscosity of the fracture fluid." It appears that in every example in which enzyme breaker is tested, a constant pH of 9.3 (Examples 2-4) or 10.3 (Examples 6-7) and a temperature of 250°F is maintained throughout the 0-14 hr (Examples 2-4; Table 2) or 0-5 hr (Examples 6-7; Table 3) test periods. A gradual decrease of viscosity is observed with each sample, with or without enzyme present. It is also noteworthy that the initial viscosity of the starting fluid is significantly higher in the presence of the breaker (col. 2, lines 61-62), demonstrating that the breaker is in communication with the fluid and affecting the fluid properties. One of ordinary skill in the art at the time Applicants' invention was made might consider that opposite behavior is put forth as examples of the invention in the *Tjon-Joe-Pin* reference. The experimental data in the cited reference is inconsistent with the use of a sequestered enzyme that is activated by a triggering signal.

In Table 2 of the *Tjon-Joe-Pin* reference, samples containing "inactive" breaker and a pH buffer show a higher initial viscosity than the control sample of polymer and crosslinker alone. However, the rate of viscosity loss is higher and the final viscosity is lower than the control sample. In Table 3, the fluid containing the enzyme-crosslinker-polymer complex also has a higher viscosity than the corresponding fluid without complex and buffer, but it maintains a higher viscosity throughout the test period. As the higher initial viscosity is the only common element, one of ordinary skill in the art, when reading Table 3 would be at a loss to understand whether the *Tjon-Joe-Pin* reference is describing a way to increase viscosity or to create increased viscosity that sometimes breaks faster and sometimes slower when held at constant conditions. In any event, neither case constitutes control of breaking rate or final viscosity by changing either pH or temperature. At col. 2, lines 35-37, the *Tjon-Joe-Pin* reference states that "[t]he complex may be maintained in a substantially non-reactive state by maintaining specific conditions of pH and temperature." As the same pH and temperature conditions are maintained throughout the experiments described in the *Tjon-Joe-Pin* reference, it appears that breaking of the fracture fluid will occur without a change in pH.

Claim 20 has been amended to depend from amended claim 3, which specifically requires encapsulation of the substrate-degrading agent <u>and</u> use of one or more of a group of triggering signals, including change in pH. For at least the same reasons as discussed above with respect to the § 102(b) rejection of claims 2 and 3, it is submitted that *Tjon-Joe-Pin* does not teach or suggest encapsulation of the enzyme and activation by any of the claimed triggering signals. Claims 31-33, which depend from claim 20 and add further limitations thereto, are believed to also be non-obvious over *Tjon-Joe-Pin* for at least the same reasons as claims 3 and 20.

With respect to claims 31-33, even if, *arguendo*, one of ordinary skill in the art would know to use an enzyme within the scope of the claims, claims 31-33 are still non-obvious over *Tjon-Joe-Pin* at least for the same reasons as discussed above with respect to claims 3 and 20. Accordingly, claims 1, 20 and 31-33 are believed to be patentable over the prior art.

<u>Additional Amendments</u>

In addition to the claim amendments described above, Applicants are currently submitting some amendments to the specification and claims which are not being made for reasons of patentability, but for clarification and better consistency with the specification, or to correct obvious errors in spelling or form. Claim 20 has been additionally amended for reasons of form. Claim 30

has been amended to make clearer that each of the at least two agents is inactivated by encapsulation. Claim 41 has been amended to correct an obvious error (the word "zone" was erroneously omitted). Claim 98 has also been amended to correct its form. Claim 103 has been amended for clarity by expressly stating that drilling fluid that is removed from said downhole environment. Claim 109 has been amended to make clearer that the applying of the triggering signal includes the downhole reversal of wellbore pressure-differential. Similarly, claim 112 has been amended to recite that applying the triggering signal includes a change in wellbore pressure-differential such that the inactivated agent is exposed to the contaminant. Claim 128 has been amended to correct a possible inconsistency in terminology.

New claim 132, which depends from claim 3, has been added to better ensure coverage of certain preferred embodiments which require that the encapsulated substrate-degrading agent is capable of responding to the triggering signal such that the agent becomes sufficiently unencapsulated to allow it to degrade the substrate. *Tjon-Joe-Pin* does not teach encapsulation and does not teach that activation of the enzyme-polymer-crosslinker complex includes unencapsulation. New claim 132 is supported in the specification at page 22, lines 18-26, for example.

New claims 133-149 are added to ensure better coverage of certain embodiments to which Applicants are entitled. Claims 133 and 134 depend from claims 44 and 49, respectively. Claims 135-149 depend from claim 1 and include limitations similar to those of amended claims 4-17 and 19, which now depend from claim 3.

New claims 150-155, which depend directly or indirectly from allowable claim 102 and add further non-obvious limitations thereto, are included to ensure better coverage of specific embodiments to which Applicants are entitled. The limitations of these claims are similar to those of claims 22-27.

New claims 156-163 have been added to better ensure coverage of specific embodiments to which Applicants are entitled. Each of those claims requires that the substrate-degrading agent (or enzyme) inactivated by sequestration (or encapsulation) is prepared prior to its containment in the fluid, or solid, or mixture.

Claims 1, 3, 40, 44, 46, 49 have been further amended to recite "and combinations thereof" which are supported in the specification at page 3, lines 6-9; page 29, lines 1-2 and in the Abstract at line 6, for example; and have been amended to include "reversal of wellbore pressure-differential" (which finds support at page 5, lines 4-18; page 16, lines 28-31; page 20, lines 4-9; and page 48, line

30 through page 49, line 8, for example). Claim 33 has been amended to recite "said substrate-degrading agent comprises at least one enzyme ... ." This limitation is supported in the specification at page 18, line 3, for example.

Each of these amendments and new claims is fully supported in the specification and/or claims as originally filed, and are believed to be patentable over the references of record for at least the same reasons discussed above, and/or depend from allowable claims.

Conclusion

Applicants may have at times referred to claim limitations in shorthand fashion, or may have focused on a particular claim element. This discussion should not be interpreted to mean that the other limitations can be ignored or dismissed. The claims must be viewed as a whole, and each limitation of the claims must be considered when determining the patentability of the claims. Moreover, it should be understood that there may be other arguments with respect to patentability which have yet to be raised, but which may be raised in the future. The format of this Amendment and Response to Office Action is believed to conform with the Revised Amendment Practice as described in "Changes To Implement Electronic Maintenance of Official Patent Application Records," 68 Fed. Reg. 38611 (June 30, 2003).

All of the pending claims are believed to be free of the prior art, and reconsideration and withdrawal of the rejections are respectfully requested. If a telephone conference would facilitate the resolution of this matter, the Examiner is invited to telephone the undersigned representative. Should any fees have been inadvertently omitted, or if any additional fees are required or have been overpaid, please appropriately charge or credit those fees to Deposit Account Number 03-2769 of Conley Rose, P.C., Houston, Texas, and consider this a petition for any necessary extension of time.

Respectfully submitted,

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ATTACHMENT A

Copy of U.S. Patent No. 5,615,739

US005615739A

United States Patent [19]

Dallas

[11] **Patent Number: 5,615,739**

[45] **Date of Patent: Apr. 1, 1997**

[54] **APPARATUS AND METHOD FOR COMPLETING AND RECOMPLETING WELLS FOR PRODUCTION**

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[21] Appl. No.: **640,335**

[22] Filed: **Apr. 30, 1996**

Related U.S. Application Data

[62] Division of Ser. No. 328,144, Oct. 21, 1994, Pat. No. 5,540,282.

[51] **Int. Cl.**[6] **E21B 43/25**

[52] **U.S. Cl.** **166/306**; 166/308

[58] **Field of Search** 166/75.13–75.15, 166/379, 381, 382, 387, 305.1, 306, 308

[56] **References Cited**

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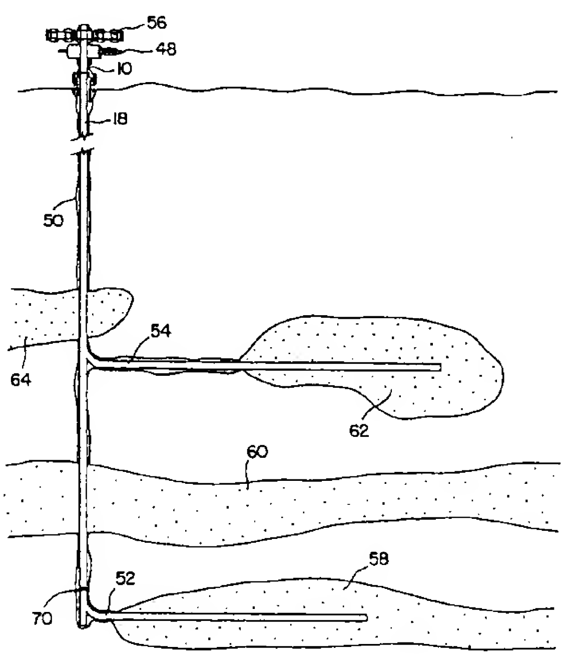
Primary Examiner—Roger J. Schoeppel
Attorney, Agent, or Firm—Dority & Manning, P.A.

[57] **ABSTRACT**

An apparatus and method for completing or recompleting wells for production is disclosed. The apparatus and method are particularly adapted to the completion of oil or gas wells having a plurality of production zones. In particular, the apparatus is useful for oil or gas wells having production zones which require stimulation prior to initial production of the well, or producing wells which require recompletion in order to open new zones or to reperforate and stimulate existing zones from which production has slowed down or ceased. The apparatus comprises a header spool having a pressure rating that is about as high as the burst pressure rating of the surface casing of the well. The header spool is mounted to a casing spool before a wellhead is placed on the well. The header spool has an internal passage which is at least as large as the diameter of the casing in the well. This permits an efficient completion of the well after the casing is cemented in. The apparatus in accordance with the invention permits the unobstructed use of a full range of tools including casing perforation tools, blowout preventers, casing plugs, logging tools, fishing tools, and other apparatus required in the completion of a well for production. The method for completing wells involves installing a header spool in accordance with the invention on the well before a wellhead is installed and performing the steps required to perforate the casing and stimulate or fracture the zones requiring treatment in order to prepare the well for production before wellhead equipment is installed. This method and apparatus permits a well to be completed at a significantly less cost than for completing a multi-zone well in the traditional manner of completing after the wellhead equipment is installed.

12 Claims, 3 Drawing Sheets



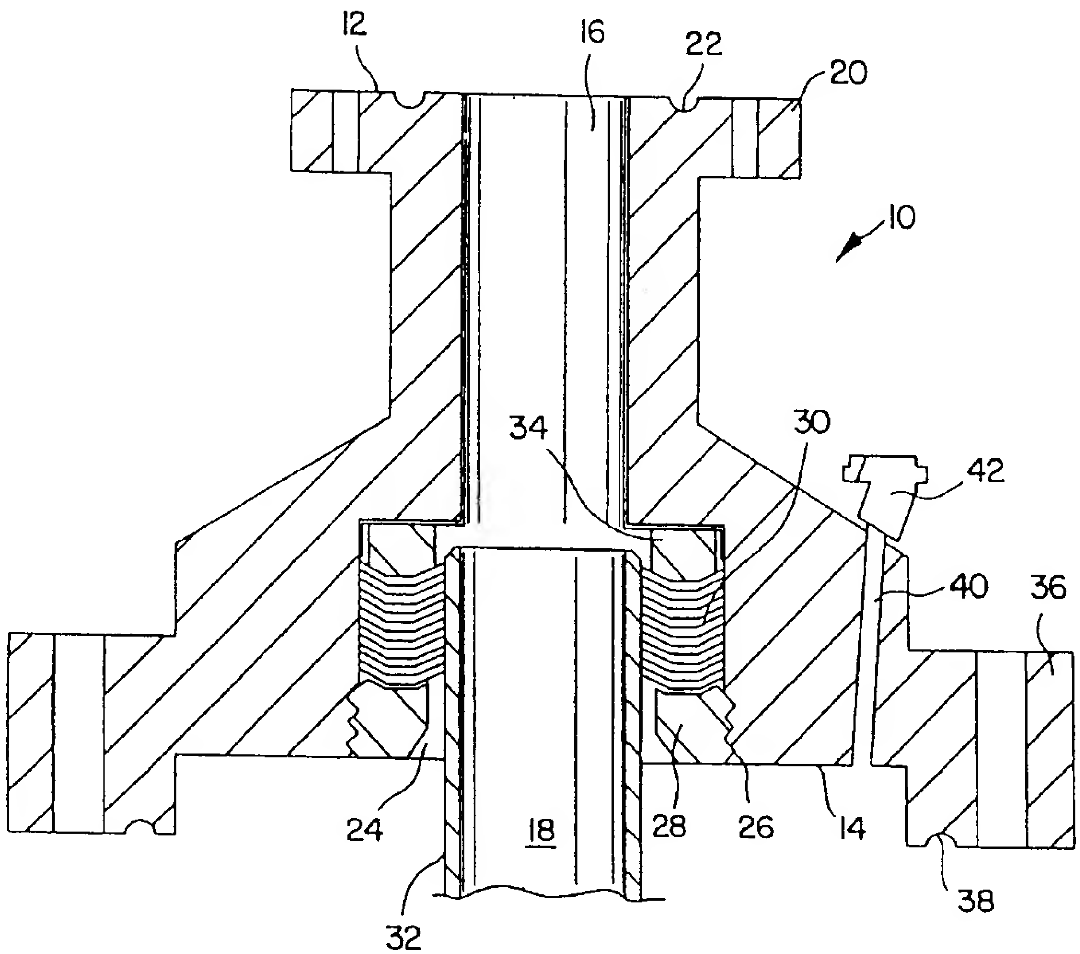


FIG. 1

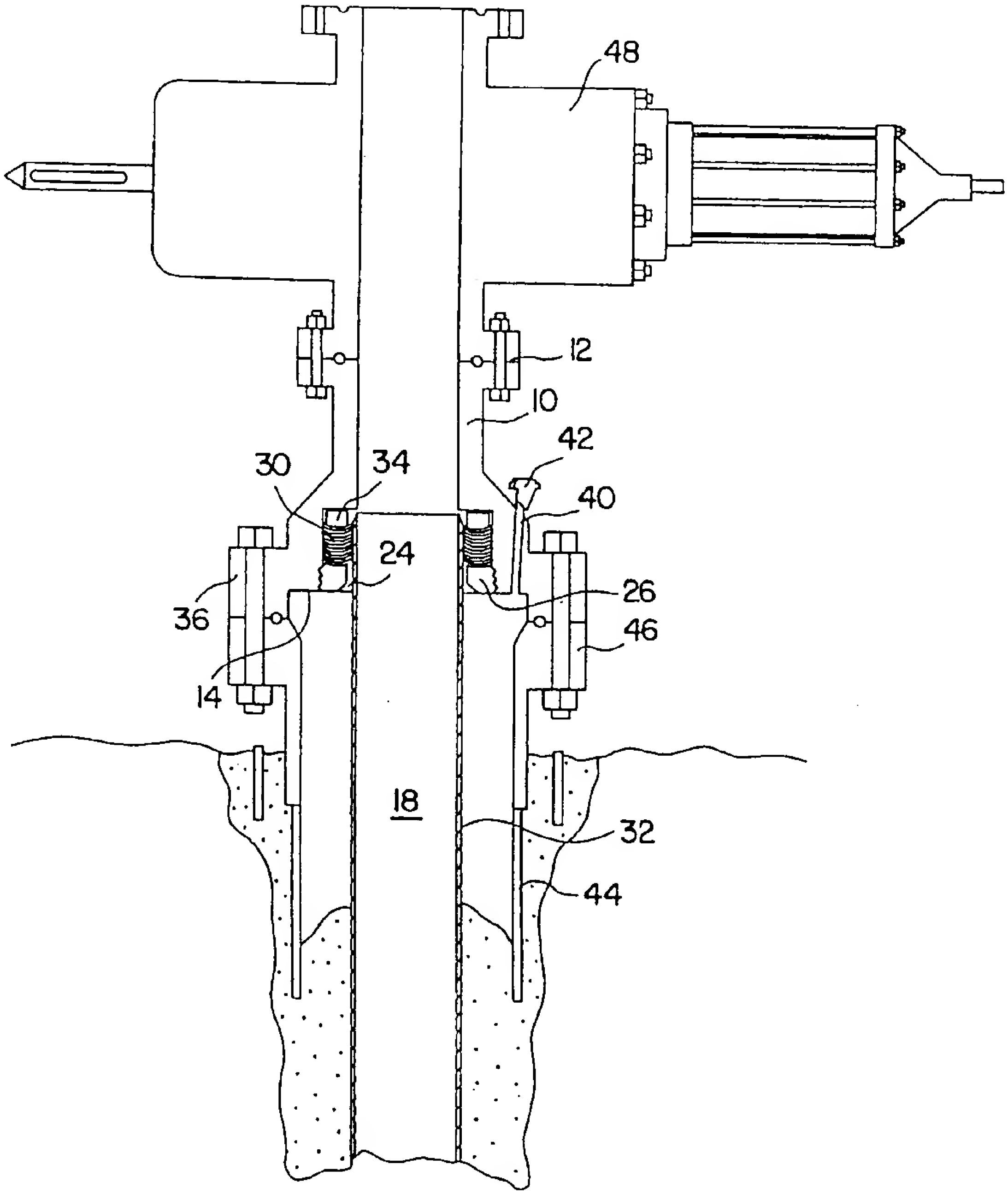


FIG. 2

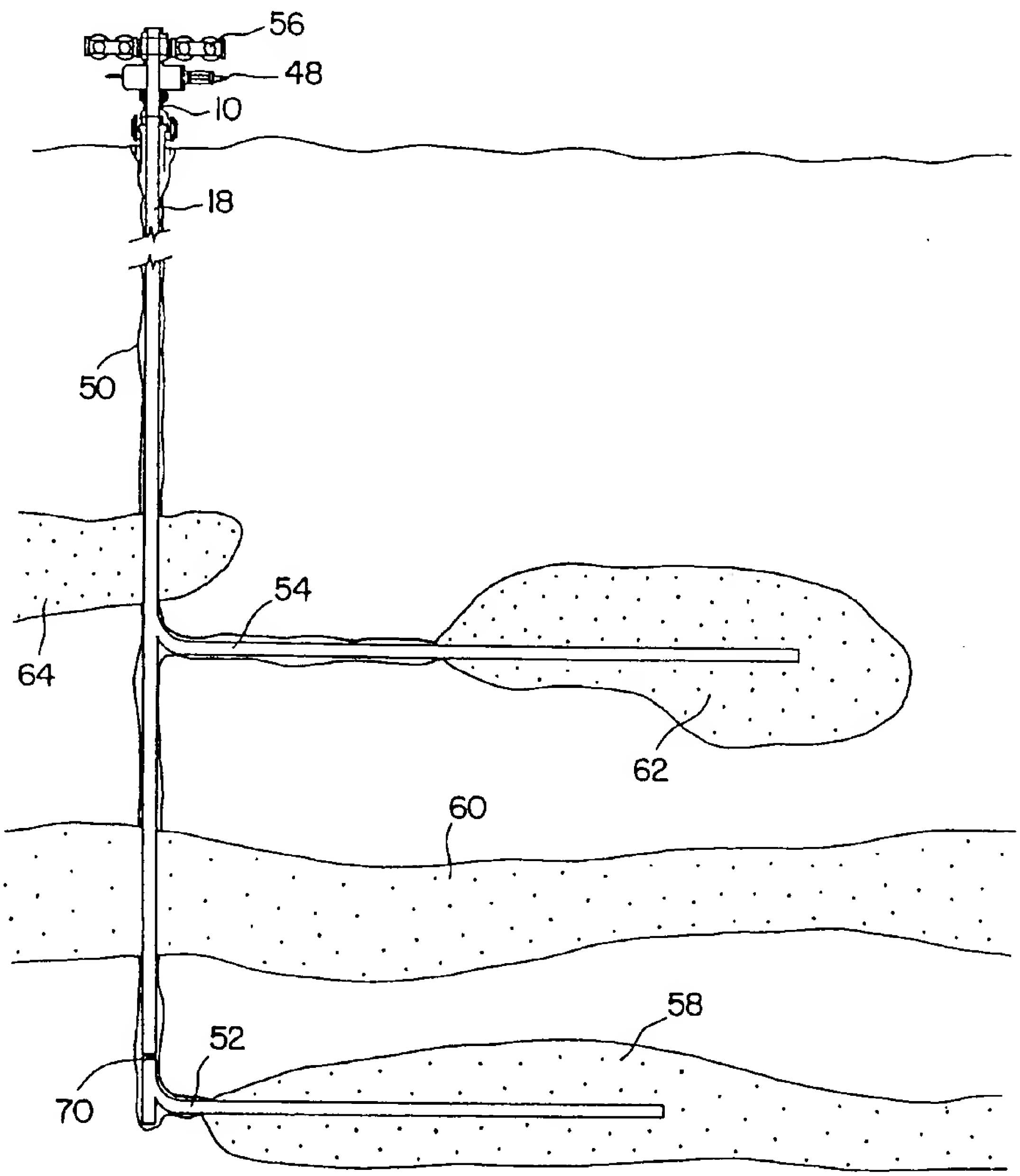


FIG. 3

APPARATUS AND METHOD FOR COMPLETING AND RECOMPLETING WELLS FOR PRODUCTION

This is a division of application Ser. No. 08/328,144, filed Oct. 21, 1994, now U.S. Pat. No. 5,540,282.

TECHNICAL FIELD

The present invention relates to wellhead equipment for oil and gas wells and, in particular, to an apparatus and improved method for completing and recompleting oil and gas wells for production.

BACKGROUND OF THE INVENTION

After an oil or gas well bore is drilled, a well casing is generally sunk in the bore and a surface casing is "cemented in" around the well casing. The well is then ready for "completion" to prepare the well for production. In the simplest instance, well completion involves installing wellhead equipment, logging the cased well to locate the production zone(s), and perforating the casing in one or more of the production zones to put the well into hydrocarbon production. Well completion may further involve the high pressure stimulation of production zone(s) in the well to promote better production from the well.

Producing wells are sometimes "recompleted" to stimulate or prolong production. Recompletion of a well involves the perforation of the well casing in the area of production zones where the casing was not perforated when the well was completed for initial production. Recompletion may also involve the high pressure stimulation of production zones associated with newly perforated and/or originally performed areas of the casing. Well completion and recompletion are both generally handled by oil and gas well service providers.

The methods for drilling and casing oil and gas wells have evolved considerably in recent years. In particular, the introduction of horizontal drilling tools and techniques, as well as the exploitation of lower yield production zones have placed new demands on oil and gas well service providers responsible for completing wells for production. Traditionally, new wells have been drilled and cased and wellhead equipment has been installed as soon as the surface casing is cemented in. Consequently, any high pressure stimulation procedures required to bring the well into production are conducted using a wellhead isolation tool to protect the wellhead from the excessive pressures, abrasives and/or caustic solutions used to stimulate the flow of hydrocarbons from the production zone(s).

While this method is often effective for stimulating producing wells to increase production, it is not a cost effective way of conditioning certain new wells for production. A problem arises because wellhead isolation tools are stroked through the wellhead equipment and therefore necessarily reduce the diameter of the passage through the wellhead. If a multi-zone well requires high pressure stimulation during completion, it is necessary to initiate a multi-stage process wherein a wellhead isolation tool is stroked through the wellhead for each high pressure stimulation operation and withdrawn between stimulation operations in order to permit perforation tools, isolation plugs and/or blowout preventers, and the like to be inserted into the well. This slows the well completion process and contributes significantly to the cost of preparing a well for production. The cost is particularly significant in deep wells having horizontal bores where tool

operations may take a significant amount of time. Service providers such as well fracturing and stimulation contractors charge transportation and setup fees as well as stimulation process fees. Long delays between a requirement for their service is therefore undesirable and expensive, especially if they must take down and move equipment between well stimulation processes for the same well.

To date, the only tool available to accomplish well completion in multi-zone wells requiring stimulation prior to production has been the wellhead isolation tools well known in the art.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an apparatus for the completion or recompletion of oil and gas wells which is safe and efficient to use.

It is a further object of the invention to provide an apparatus for the completion or recompletion of oil and gas wells which permits the use of any tool that can be used in the casing of the well.

It is a further object of the invention to provide a method of completing oil and gas wells for production which permits tool operation and stimulation processes to proceed in an uninterrupted sequence.

It is a further object of the invention to provide a method and apparatus which permits multi-production zone wells to be completed or recompleted considerably more economically than was previously possible.

In accordance with the invention, there is provided an apparatus for completing and recompleting oil and gas wells for production, comprising:

a header spool for sealingly engaging an outer perimeter of a dressed top end of a casing in the well, the header spool having an upper end, a lower end and a passage which extends between the upper end and the lower end, the passage having a diameter which is at least equal to an inner diameter of the casing;

the upper end being adapted to accommodate means for providing a fluid tight attachment of a high pressure valve for controlling a flow of liquids and gases through the axial passage;

the lower end including an annular recess that is coaxial with the axial passage and extends upwardly from the lower end, the annular recess being adapted to accommodate packing for providing a fluid seal between an outer surface of the casing and the header spool when the header spool is installed on the casing in the well;

a retainer means for retaining the packing in the annular recess, the retainer means being adapted to slide over the casing;

the lower end further including a flange adapted for connection to a surface casing spool of the well, the flange being adapted to accommodate means for providing a fluid seal between the header spool and the surface casing spool; and

a pressure test port which extends through the lower end of the header spool in an area located between the annular recess and the flange, whereby the pressure test port may be monitored to ensure that pressurized fluids do not pass between the packing and the well casing or the packing and the header spool during a well completion or a well recompletion operation.

In accordance with a further aspect of the invention, there is provided a method of completing oil and gas wells for production, comprising the steps of:

a) mounting a header spool to a surface casing spool of the cased, unheaded well, the header spool having a pressure rating which is at least about equal to the pressure burst strength of a casing in the well, an internal passage communicating with the casing having a diameter at least as large as the internal diameter of the casing, the internal passage being closed at an upper end by a high pressure valve having a gate with a diameter that is at least as large as the diameter of the casing, the header spool including a pressure test port located between a flange for mounting the header spool to the casing spool and the internal passage, and the header spool engaging a top end of the casing in a fluid tight seal adapted to contain pressurized fluids up to pressures about equal to the burst strength of the casing;

b) pressurizing the well to test the seal between the header spool and the casing;

c) inserting a casing perforation tool through the high pressure valve, the header spool and the casing and perforating the casing in the area of a first production zone;

d) extracting the casing perforation tool from the casing, the header spool and the high pressure valve;

e) connecting a stimulation line to the high pressure valve, if stimulation of the first production zone is required, and injecting stimulation fluids or proppants into the first production zone;

f) monitoring the pressure test port to ensure that pressurized stimulation fluids do not escape the seal between the header spool and the casing;

g) inserting an isolation plug into the casing to isolate the first production zone from a balance of the casing;

i) repeating steps b) through f) for each additional production zone of the well;

j) depressurizing the casing to normal well pressure;

k) plugging the casing in an instance when normal well pressure is greater than atmospheric pressure at the top of the well casing; and

l) removing the header spool from the surface casing spool and the well casing.

The invention therefore provides an apparatus and a method for completing and/or recompleting oil and gas wells for production. The apparatus consists of a header spool which may be connected to the top end of a casing that is upset and beveled, as normally done for the installation of wellhead equipment. The header spool is preferably constructed to have a pressure rating which is at least about equal to the casing burst pressure. The header spool is designed to provide a fluid tight seal with the casing when it is mounted on a casing spool. The fluid tight seal is provided by chevron packing which is installed in an annular recess in the base of the header spool. The chevron packing is retained in the annular recess by a hollow packing nut that slides over the casing. A pressure test port extends through the lower end of the header spool in an area located between the annular recess and a flange for attaching the header spool to a surface casing spool. The pressure test port is monitored to ensure that pressurized gases and fluids do not escape from the casing by passing between the packing and the casing or the packing and the header spool during a well stimulation operation.

The method in accordance with the invention permits well completion processes to be conducted in an uninterrupted sequence because any tool that can be used in the casing can be introduced through the header spool without restriction. In accordance with the method, the header spool is mounted to an unheaded well requiring completion or recompletion. A high pressure valve, which is preferably a hydraulic valve capable of containing pressures equal to or exceeding the casing burst pressure, is then installed on the header spool. Pressurized fluid is injected into the well to test the seal around the casing. The pressure test port is monitored to ensure that the chevron packing does not leak. Once the seal has been verified, the pressure is permitted to backflow from the well and well completion commences. Well completion in a multi-production zone well usually involves at least the steps of logging a production zone to be completed; perforating the logged zone; stimulating the perforated zone, if necessary; backflowing the stimulation fluids; testing production, if desired; inserting an isolation plug to isolate the prepared zone, if necessary; and, repeating the process until all zones of the well have been prepared for production.

The uninterrupted processing of well completion or recompletion is considerably more efficient and cost effective than prior methods using wellhead equipment and wellhead isolation tools. Previously, it was necessary to set the wellhead isolation tool for each stimulation process and remove the tool for other completion steps because logging tools, casing perforation tools, packers, blowout preventers, and other tools and equipment could not be inserted into the casing through a wellhead isolation tool.

The apparatus and method in accordance with the invention therefore permits the exploitation of wells which were heretofore economically unfeasible to complete for production. The apparatus and method also permit the economical recompletion of producing wells to stimulate or prolong production.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained by way of example only and with reference to the drawings, wherein:

FIG. 1 is a cross-sectional view of a header spool in accordance with the invention mounted to a top of a well casing to permit a well completion or recompletion operation;

FIG. 2 is a cross-sectional view of the header spool shown in FIG. 1 installed on a surface casing spool of an unheaded well, the header spool having a high pressure valve mounted thereto in preparation for a well completion or recompletion operation; and

FIG. 3 is a schematic diagram of an apparatus in accordance with the invention mounted to a well that includes horizontal bores, the well being in a condition to be completed for production.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a cross-sectional view of a header spool in accordance with the invention, generally indicated by the reference **10**. The header spool has an upper end **12**, a lower end **14** and a passage **16** which extends between the upper end and the lower end. The passage **16** has a diameter which is at least equal to an inner diameter of a casing **18** to which the header spool **10** is connected. The upper end **12** is provided with a top flange **20** preferably having an annular groove **22** for accommodating a high pressure O-ring (not illustrated). The flange **20** is used to attach a high pressure valve for controlling fluid flow from the casing **18**, as will be explained below with reference to FIG. **2**.

The lower end 14 of the header spool 10 includes an annular recess 24 that is coaxial with the passage 16 and extends upwardly from the lower end 14. The annular recess 24 preferably includes a spiral thread 26 in its lower end. The spiral thread retains a hollow retainer nut 28 for supporting a donut-shaped packing 30 for providing a fluid seal between an outer surface 32 of casing 18 and the header spool 10. The packing 30 is preferably a chevron packing, well known in the art. Positioned above the packing is a steel spacer ring 34 for spacing the packing 30 away from a top of the annular recess 24 and ensuring good compression of the packing 30 by the hollow retainer nut 28. As is apparent, the hollow retainer nut 28 is sized to slide over the outer surface 32 of the casing 18 without scoring or abrading the casing.

The lower end 14 of the header spool 10 also includes a bottom flange 36 used to mount the header spool to a surface casing flange as will be explained below. The bottom flange 36 preferably includes an annular groove 38 for accepting a high pressure O-ring (not illustrated) to provide a fluid seal between the header spool 10 and the casing spool to which the header spool is mounted. The header spool further includes a pressure test port 40 which extends through the lower end 14 of the header spool 10 in an area located between the annular recess 24 and the flange 36. Fluid flow through the test port 40 is preferably controlled by a pressure release valve 42, commonly commercially available.

The pressure test port 40 is used to monitor the fluid seal between the header spool 10 and the casing 18 during well completion and recompletion operations, as will be explained below in relation to FIGS. 2 and 3. The header spool 10 is preferably constructed to withstand fluid pressures about equal to the burst pressure rating of the casing 18 so that well stimulation operations can be conducted at the maximum pressure to which the well can be safely subjected, if desired.

FIG. 2 shows a header spool 10 in accordance with the invention mounted to an unheaded well casing 18. The well has been drilled, the casing 18 has been sunk in the bore and a surface casing 44 has been "cemented in" in a process well known in the art. The surface casing 44 includes a surface casing spool 46 adapted to support wellhead equipment when the well is completed and ready for production. The header spool 10 is mounted to the casing spool 46 after the well casing 18 has been upset, beveled and cleaned up in a well known manner for preparing a casing for the installation of wellhead equipment. Before the header spool 10 is mounted to the casing spool 46, the spacer ring 34, the chevron packing 30 and the retainer nut 26 are installed in the annular recess 24 in the lower end 14 of the header spool 10. The retainer nut 26 is tightened to securely support the chevron packing 30 in its position. To install the header spool 10, the header spool is carefully lowered over the beveled casing 18 and the chevron packing is forced over the top of the casing to provide a fluid tight seal. Because of the structure of the chevron packing, it is capable of providing a seal that will contain extreme pressures. After the header spool 10 is mounted to the casing 18, it is bolted down to the surface casing spool 46. A high pressure valve 48 is then mounted to the upper end 12 of the header spool 10. The high pressure valve 18 must be capable of containing elevated fluid pressures and preferably has a pressure rating that is about equal to the pressure burst rating of the casing 18. Such valves are normally hydraulically operated and are commercially available. After the high pressure valve 48 is mounted to the header spool 10, the installation is ready for pressure testing and well completion operations as explained below.

Those skilled in the art will perceive that the header spool 10, normally pressure rated for at least 10,000 psi, is bolted to a surface casing spool 46 normally pressure rated for 3–5,000 psi. It must be understood, however, that the surface casing spool is completely isolated from direct fluid pressures because the pressure test port 40 is normally open during pressure testing and well completion or recompletion operations. The surface casing spool is therefore only subjected to a vertical lifting force translated through the header spool 10 from the fluid pressures contained by the high pressure valve 48. Furthermore, since the cross-sectional area of the casing is considerably smaller than the cross-sectional area at the flange of the surface casing spool 46, the vertical lifting force is distributed over a large area and the surface casing spool 46 can readily withstand the vertical strain of holding down the header spool 10.

FIG. 3 shows a schematic view of a cased well having a configuration exemplary of a well configuration particularly adapted for completion using the apparatus and methods in accordance with the invention. The well includes a vertical bore 50, a lower horizontal bore 52 and an upper horizontal bore 54. The apparatus in accordance with the invention may be used to complete any well, regardless of the orientation of the bores. Use of the apparatus and method are particularly beneficial when the well has one or more production zones that require high pressure stimulation, and the production zone(s) are too voluminous in combination to be stimulated in a single high pressure acidizing or fracturing process.

As shown in FIG. 3, a header spool 10 has been mounted to the cased, unheaded well. Mounted to the header spool 10 is a high pressure valve 48. Mounted above the high pressure valve 48 is an optional fracturing cross connection 56, commonly referred to as a "frac cross" or a "goats head", and referred to as a frac cross below.

The invention encompasses a method of completing a cased well for production. A typical series of events in the completion of a well for production, such as the well shown in FIG. 3, proceeds as follows:

1) The fluid tight seal at the header spool 10 is tested by connecting a high pressure pump, typically a "frac pump" (high pressure fracturing pump) to the high pressure valve 48 or the frac cross 56. The cased well is pressurized to the maximum pressure desired for the stimulation process to be conducted on the well (typically 6–10,000 psi). The pressure release valve 42 on the pressure test port 40 (see FIG. 2) is opened to ensure that the chevron packing 30 maintains a fluid tight seal around the well casing 18. If no fluid escapes when the pressure release valve 42 is opened, the fluid tight seal is known to be secure. Normally, the pressure release valve 42 is left open during well completion operations so that any leak around the chevron packing 30 is instantly detected.

2) The test fluid pressure is released from the well and a log tool is lowered on a wire line into the well to log the most remote zone in the well bore. For instance, it may be determined that a first production zone 58 requires stimulation to maximize production. After the logging of the zone 58 is completed and the log is analyzed, a casing perforation tool, hereinafter referred to as a "perf gun" (not illustrated) is mounted to a top of the frac cross 56 or the high pressure valve 48 and lowered by wire line into the well to the first production zone 58. The casing is then perforated in that zone or a portion of the zone. The perf gun is then removed from the

well. One or two fracturing lines (not illustrated) are connected to the frac cross **56** or the high pressure valve **48**. A high pressure stimulation cycle wherein acidic and/or abrasive fluids are pumped under elevated pressures (6–10,000 psi) into the first production zone **58** is performed. After a target stimulation pressure is achieved in the well, the stimulation fluid in the well is permitted to flow back through the header spool **10** and the high pressure valve **48**. The well may then be tested to determine the hydrocarbon flow rate from the production zone, or testing may be postponed until the well completion operation is completed. In order to permit the stimulation of a second zone **60**, an isolation plug or packer **70** must be positioned between the production zone **58** and the production zone **60**. A packer tool is therefore lowered in the well to position the packer or plug **70**. Subsequently, the second production zone **60** is logged by lowering a logging tool into the well casing, and the entire sequence of the process is repeated for each of the production zones **60**, **62** and **64**.

The advantage of this method is that the header spool **10** permits the unobstructed use of any tool which can be used in the casing **18**. Well completion procedures can therefore proceed in an uninterrupted sequence. The method therefore provides considerable economy in completing a well for production.

It should also be understood that production tubing, either jointed or continuous tubing, can be run through the header spool **10** into the casing **18**. This permits more sophisticated well completion or recompletion operations including reverse circulation in the case of a "screen out" during a stimulation process, manifolded stimulation processes, etc. which can contribute to more efficient and reliable well completion or recompletion procedures.

After the well is completed, stimulation fluids used to stimulate the uppermost production zone treated are permitted to flow back through the header spool **10** and the high pressure valve **48**. A packer is then set at the top of the well bore and the header spool **10** is removed from the surface casing spool **46**. A wellhead assembly is then mounted to the wellhead; one or more blowout preventers are installed and the well is cleaned before commencing production. Typically, a tubing hanger is installed before the wellhead equipment is installed and production tubing is run into the wellhead before hydrocarbon production is commenced.

While the method of using the header spool in accordance with the invention has been explained in relation to the completion of a cased, unheaded well for production, it will be understood by those skilled in the art that the header spool **10** in accordance with the invention may also be used for recompletion of existing wells having a plurality of production zones which require stimulation and/or which require perforation and stimulation of production zones in unperforated areas of the well casing. In using the header spool **10** for recompletion operations, the procedures described above are typically followed in the same sequence as practiced for completing a newly cased well.

The embodiments of the invention described above are intended to be exemplary only, the scope of the invention being limited solely by the scope of the appended claims.

I claim:

1. A method of completing oil and gas wells for production, comprising the steps of:

a) mounting a header spool to a casing spool of a cased, unheaded well, the header spool having a pressure rating which is at least about equal to the pressure burst strength of a casing in the well, an internal passage communicating with the casing and a diameter at least as large as the internal diameter of the casing, the internal passage being closed at an upper end by a high pressure valve having a gate at least as large as the diameter of the casing, the header spool including a pressure test port located between a flange for mounting the header spool to the casing spool and the internal passage, and the header spool engaging a top end of the casing in a fluid tight seal adapted to contain pressurized fluids up to pressures about equal to the burst strength of the casing;

b) pressurizing the well to test the seal between the header spool and the casing;

c) inserting a casing perforation tool through the high pressure valve, the header spool and the casing and perforating the casing in a first production zone;

d) extracting the casing perforation tool from the casing, the header spool and the high pressure valve;

e) connecting a stimulation line to the high pressure valve, if necessary, and injecting stimulation fluids or proppants into the first production zone;

f) monitoring the pressure test port to ensure that pressurized stimulation fluids do not escape the seal between the header spool and the casing;

g) inserting an isolation plug into the casing to isolate the first production zone from a balance of the casing;

i) repeating steps b) through f) for each additional production zone of the well;

j) depressurizing the casing to normal well pressure;

k) plugging the casing in an instance when normal well pressure is greater than atmospheric pressure at the top of the well casing; and

l) removing the header spool from the casing spool and the well casing.

2. A method of completing oil and gas wells for production as claimed in claim **1** wherein the method further includes the step of logging the cased well using a logging tool prior to inserting the casing perforation tool through the high pressure valve.

3. A method of completing oil and gas wells for production as claimed in claim **1** wherein the method further includes the step of testing the production zone for hydrocarbon production after stimulation of the production zone.

4. A method of completing oil and gas wells as claimed in claim **1**, wherein the method further includes a step of running production tubing through the header spool after step d) and prior to step e).

5. A method of completing oil and gas wells as claimed in claim **4** wherein the production tubing is a jointed tubing.

6. A method of completing oil and gas wells as claimed in claim **4** wherein the production tubing is a continuous tubing.

7. A method of recompleting oil and gas wells for production, comprising the steps of:

a) plugging a top end of a well casing of a cased, headed oil or gas well to isolate the wellhead equipment from any natural pressure in the well;

b) removing the wellhead equipment from the well;

c) mounting a header spool to a casing spool of the cased, unheaded well, the header spool having a pressure rating which is at least about equal to the pressure burst strength of a casing in the well, an internal passage communicating with the casing and a diameter at least as large as the internal diameter of the casing, the internal passage being closed at an upper end by a high

pressure valve having a gate at least as large as the diameter of the casing, the header spool including a pressure test port located between a flange for mounting the header spool to the casing spool and the internal passage, and the header spool engaging a top end of the casing in a fluid tight seal adapted to contain pressurized fluids up to pressures about equal to the burst strength of the casing;

d) unplugging the top end of the well casing;

e) pressurizing the well to test the seal between the header spool and the casing;

f) inserting a casing perforation tool through the high pressure valve, the header spool and the casing and perforating the casing in a first production zone, if necessary;

g) extracting the casing perforation tool from the casing, the header spool and the high pressure valve;

h) connecting a stimulation line to the high pressure valve, if necessary, and injecting stimulation fluids or proppants into the first production zone;

i) monitoring the pressure test port to ensure that pressurized stimulation fluids do not escape the seal between the header spool and the casing;

j) inserting an isolation plug into the casing to isolate the first production zone from a balance of the casing;

k) repeating steps e) through i) for each additional production zone of the well;

l) depressurizing the casing to normal well pressure;

m) plugging the casing in an instance when normal pressure is greater than atmospheric pressure at the top of the well casing; and

n) removing the header spool from the casing spool and the well casing.

8. The method of recompleting oil and gas wells for production as claimed in claim 7 wherein the method further includes the step of logging the cased well using a logging tool prior to inserting the casing perforation tool through the high pressure valve.

9. A method of recompleting oil and gas wells for production as claimed in claim 7 wherein the method further includes the step of testing the production zone for hydrocarbon production after stimulation of the production zone.

10. A method of recompleting oil and gas wells as claimed in claim 7 wherein the method further includes a step of running production tubing through the header spool and after step h) and prior to step i).

11. A method of recompleting oil and gas wells as claimed in claim **10** wherein the production tubing is a jointed tubing.

12. A method of recompleting oil and gas wells as claimed in claim **10** wherein the production tubing is a continuous tubing.

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